What Physics Needs from RF/SRF (CEBAF)

Jay Benesch

29 January 2020

Corrected by Tom Powers

29 January 2020

Additions at beginning 25 Jan 2021 Jay Benesch

Timeline

- 2005: C100 input Q defined in TN-05-044 under assumption 1 MW total power limit would be maintained (32E6 +-20%)
- 2007: Environmental Assessment allowed 1 MW each to Halls A and C as long as annual boundary limit is not exceeded.
- 2007: Project Management had FONSI worded ambiguously implying 1 MW limit continued rather than changing project spec including input Q of C100s
- 2017: Input Q specified in TN-17-055 as 20E6+-15%, again ignoring 2007 EA power limit
- 29 January 2020: Benesch presented his Powers-corrected Physics need talk to Friday SRF meeting

Physics requirement

- Email 22 Jan 2021 from Thia Keppel: “It is certainly the case that Halls A and C both will need high current. It is critical to both programs - and one major reason why users submit proposals to these Halls. If we run as proposed, there will be times when greater than 70 uAmps in Hall A and 60 uAmps in Hall C would be required. However, I think that we could live with 70/60 in the MOLLER era. Any less will have serious, negative impact.”
- It follows that at least 650 uA and up to 800 uA must be accommodated by the C75 and C100 modules. This requires that input Q be lowered.

Stub Tuners

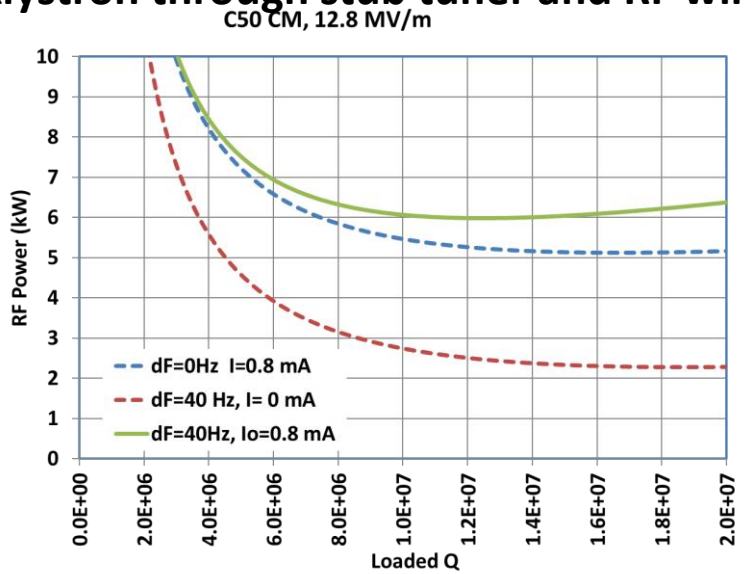
- The installed stub tuners, with stubs in the wide waveguide wall, have never successfully been used to lower cavity input Q.
- Referring to the MIT Rad Lab series available on our web site, I learned that stub tuners with stubs in wide walls are appropriate for raising Q and those with stubs in the narrow wall for lowering Q.
- Rick Nelson got a quote from Mega: $2165 each, quantity 8
- For 15 zones, 12 C100 including P1 and three C75, cost $260K if no further quantity discount.
- Labor about two person-days per tuner to remove useless installed tuner and replace it with the proper one. Cost ~$250K

Other things needed for higher power

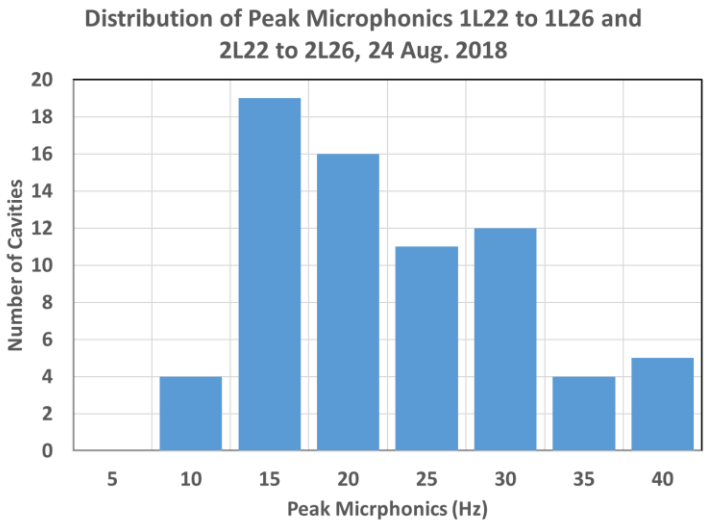
- EHS Department is working with DOE site office and ultimately Oak Ridge to get all the paperwork aligned to Environmental Assessment
- Beam dump cooling towers heat exchanger limits total to 1.1 MW
- Heat exchanger upgrade to 2 MW ~$500K per Carroll Jones, two years to bring on line after decision is made.
- BBU instability may limit current due to inadequacy of HOM damping in C100 design and execution. If single cavities within one or two C100 modules are found to be an issue, these should be replaced with drifts.
- A 1.1 MW test was planned for the end of the 2020 run before the pandemic. The 2021 schedule precludes it as well. Decision should be made ASAP, without the test.

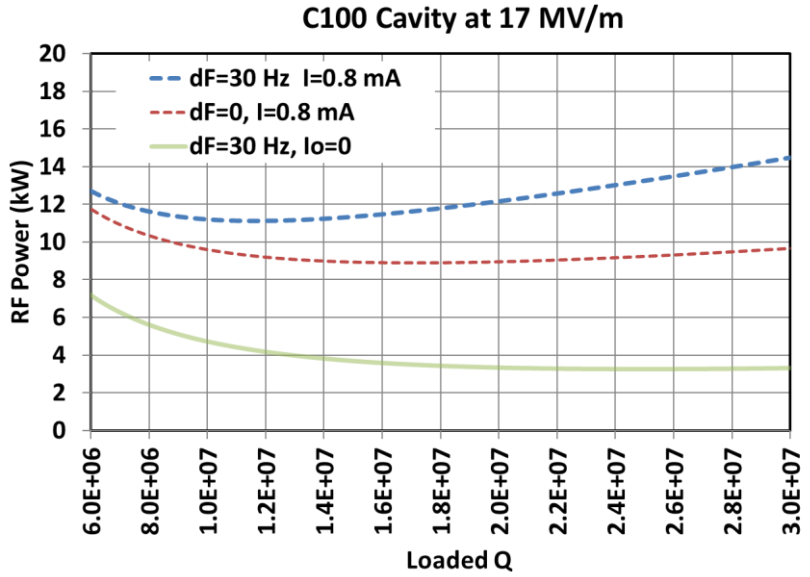
Tom Powers slide from Jan 2020: Possible paths

- **Distort sheet metal of C20 FPCs to reach ~~QL 1.3E7~~ 1E7 >QL > 1.6E7 yielding ~~C60~~ C51 after refurbishment, the higher side is better for lower current operation.**
- **Failing that, existing E-wall stub tuners to raise QL**
- **For 800 uA of current and C100 CMs. I seriously doubt that this is a good idea.**
  - **The best that you can get out of some of the C100 CMs with the microphonics that we have is 16 MV/m or about 90 MeV. (1L22, 1L24, 1L25, 2L24) for these QL should be about 9E6.**
  - **With microphonics hardening, etc. we MIGHT be able to get them to 95 MeV on most of the zones to 17 MV/m with loaded Q's of 1.2E7.**
  - **Note that a substantial fraction of the C100 klystrons do not make 12 kW.**
- **Some zones H-wall stub tuner to lower QL of C100s and extent C75s to reach specified Rc. Modeling of system from klystron through stub tuner and RF windows to cavity required.**



C50 at 12.8 MV/m





C100 at 17 MV/m

Proposed Qext spec

- Sheet metal input Q target for C50 cavities should be 7E6 with stub tuners used to take actual up to the range 8.3E6 to 9.1E6 (assumes ±30% spread around target.)
- If target input Q of C75 cavities can be lowered in sheet metal to 15E6, this should done. Stub tuners would then lower input Q to 11.1E6 (BW 135 Hz) or as close to that as possible
- Stub tuners should be used to lower input Q of C100 cavities to 11.1E6 (BW 135 Hz) or as close to that as possible

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Goal: Complete most of NP program by 2030

(Jay's Original Slide)

- **Halls A and C each need 75-80 μA five pass.**
- **Hall D for Kaon factory 5 μA 5.5 passes**
- **Total ~800 μA in each linac, NOT 450 μA**
- **Environmental Assessment was done for 1 MW each to A and C, 60**
- **kW to D, ~2 MW recirculating power in LERF, ~10 kW in UITF**
- **SOLID not included, hence most**

Klystron Power C50 Shape

- Needed: ~~0.25*L(E+IRc)2/Rc~~ Jay forgot microphoncis and detune budget

$$P_{RF} = \frac{L}{4R_c}\left\{(E + IR_c)^2 + \left(2Q_L\frac{\delta f}{f_o}E\right)^2\right\} \qquad R_C = Q_L(r/Q)$$

- Assume coupled impedance Rc = 1.25E10Ω, L = 0.5m, δf = 40 Hz, (r/Q) = 960, QL = 1.3e7,
- DeltaF based on measured values in 1L13 for C75/C50 CM.
- At 12.3 MV/m, P= 6.2 kW.
- At 15 MV/m, P= 8 kW ~~P=0.125*(1.5E7+0.8E-3*1.25E10)2/1.25E10=6.25kW~~
- At 20 MV/m, ~~P=9 kW~~ P= 11.8 kW
- ~~driving existing form factor tubes harder~~
- For 15 MV/m this means buying new 8 kW tubes and upgrading the zones at
  - $50k per zone assuming we are using the standing order for the tubes,
  - $450k if we order new tubes independently.
- For 12 MV/m this means spending $5k per zone and completing the main distribution panel upgrades in order to get 6.5 kW.

Possible paths

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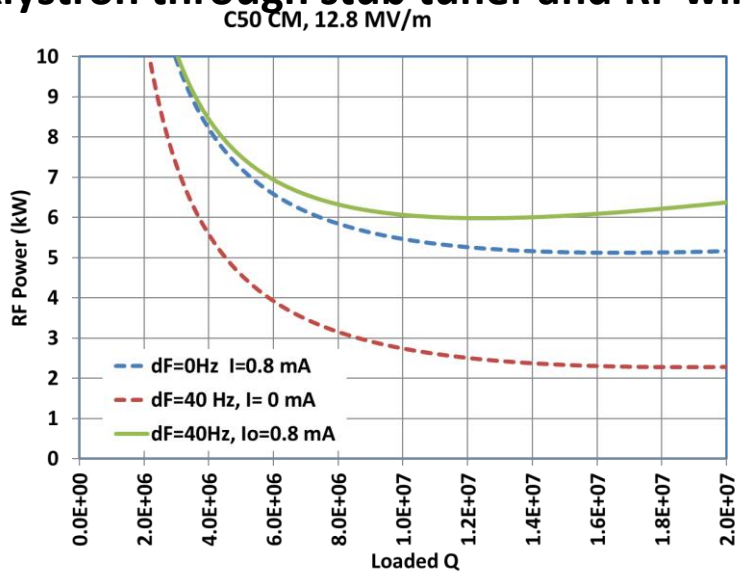
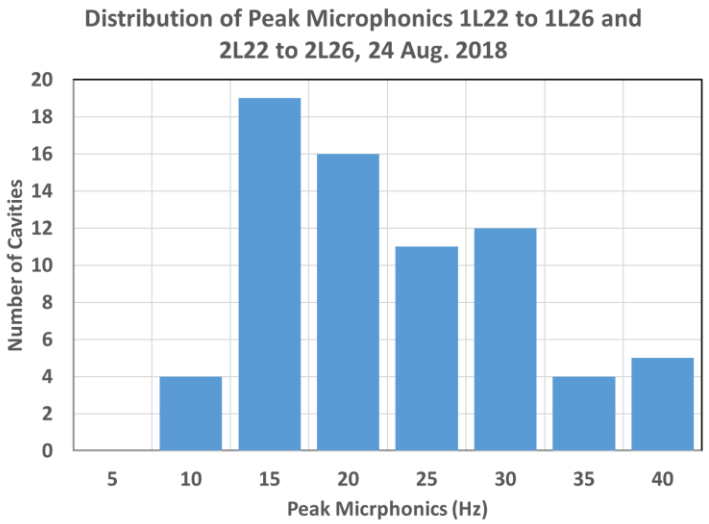
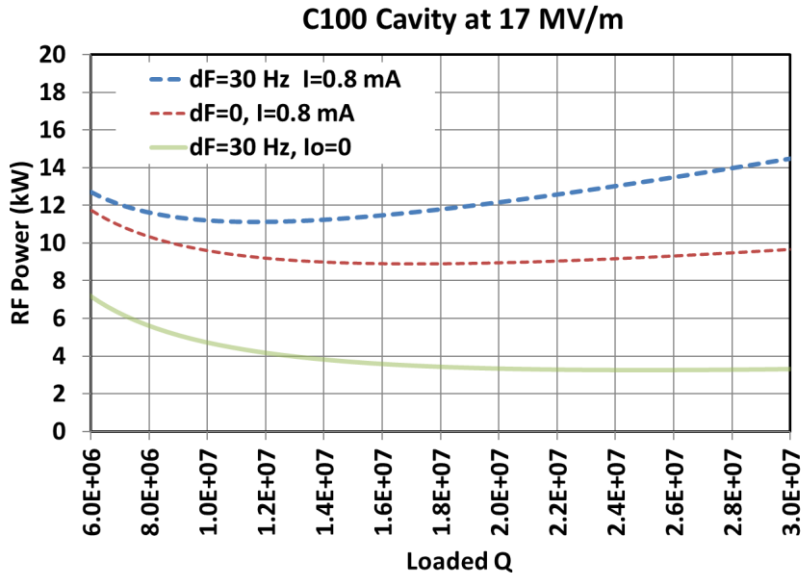
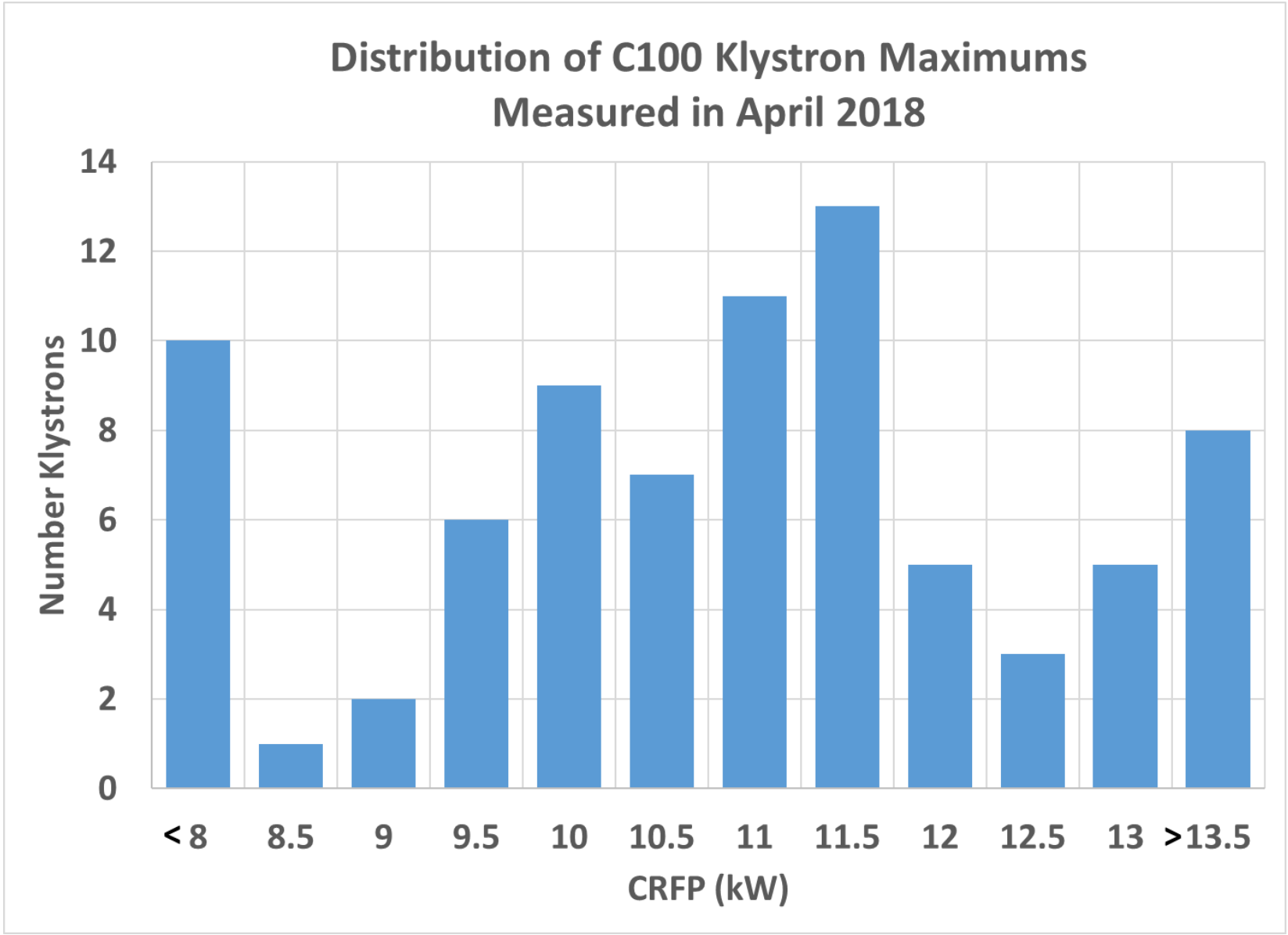


C50 at 12.8 MV/m

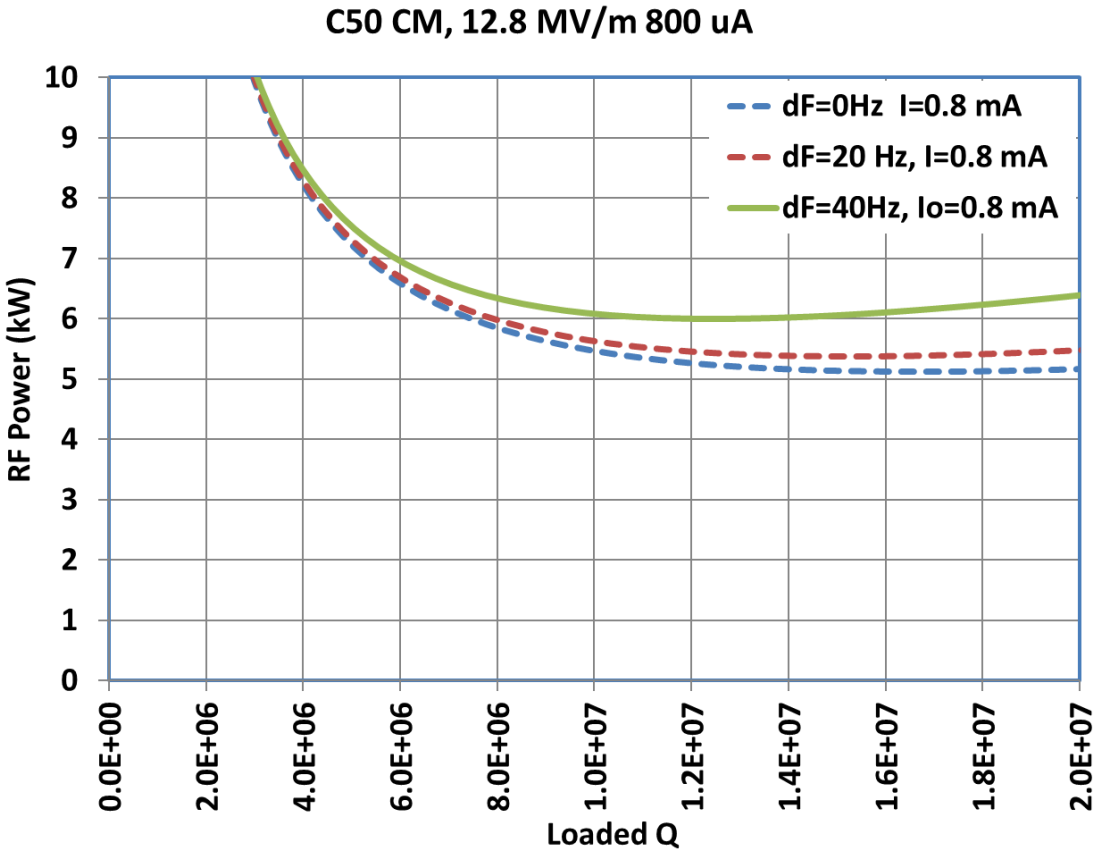


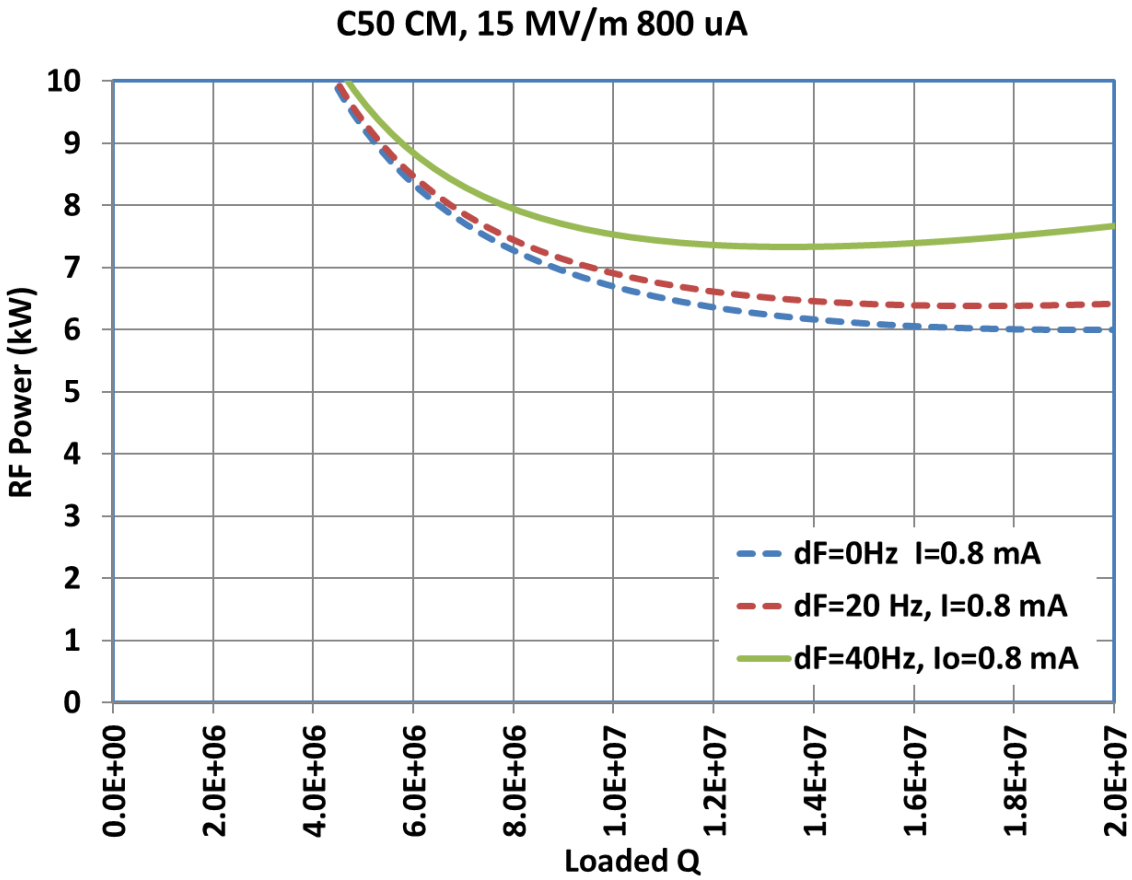


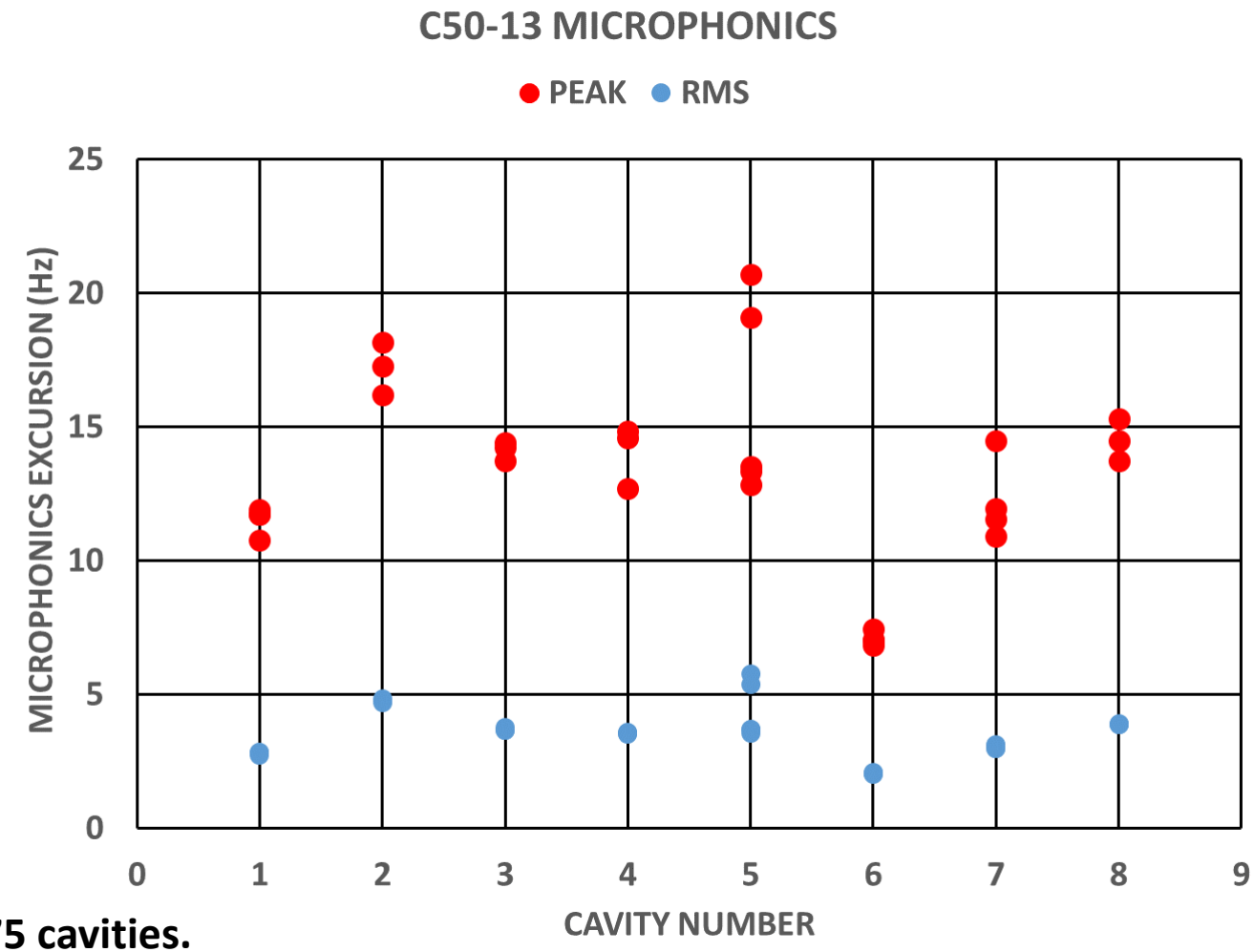
C100 at 17 MV/m


Distribution of C100 Klystron Maximums
Measured in April 2018
Number Klystrons
0
2
4
6
8
10
12
14
< 8
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
>13.5
CRFP (kW)

Comparison of required RF power as a function of loaded-Q for C50 cavities operated at 12.8 MV/m and 15 MV/m with 0, 20 and 40 Hz detune allowance.







- Cavity 1 and 2 are C75 cavities.
- These were sets of 3 minute measurements which probably missed peak excursions which occur from time to time in the machine.
- You have to add some extra detune margin to account for
  - The tuner algorithm dead band of 5 to 10 degrees.
  - Our ability to accurately set the detune offset.
  - Known and unknown sources such turbo pumps.